MEASUREMENT OF IRRIGATION EFFICIENCIES IN THE BORDER IRRIGATION METHOD UNDER EXISTING CONDITIONS

by

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(RAMADHAR SINGH)

ABSTRACT

There is a large scope in improving irrigation efficiency by introducing improved traditional methods. Border method of surface irrigation is being used in most part of the country. With the proper development of design and evaluation procedures,the border irrigation could be efficient, effective and economical type of irrigation.

The experiments were conducted at Agronomy research plot of A.A.I. farm in months of Feb.-March 1983, when crop was in flowering and milky stage of its growth, to evaluate the irrigation effciencies for the existing border irrigation system for wheat crop.

In order to determine the application of water,soil parameters such as infiltration characteristics, field capacity and bulk density were determined in all the three selected borders separately. Similarly water application, stroge and distribution efficiencies were estimated in order to ascertain the exact amount of water to be diverted from the source, in order to fulfil irrigation requirements.

Two discharge rates 2.46 lit/sec and 2.91 lit/sec were applied and water application, storage and distribution efficiencies were estimated (86.9%, 91.85%), (76.42%,77,34%) and (75.46%, 87.8%) during first and second irrigation respectively. Bulk density (r) was estimated 1.58 gms/cc and the values of the constants a and b in infiltration equation ($y= at^b$) were estimated as 0.59 and 0.44 respectively.

Field capacity was estimated 22.5%.

The obtained values of irrigation efficiencies indicate that size of borders was appropriate, proper land topography, uniform bed of the field and efficient utilization of available water supply under specific conditions.

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ABBREVIATIONS AND SYMBOLS

A S A E	- American Society of Agricultural Engineering.
Agril. Engg.	- Agricultural Engineering.
Accu	- Accumulated
cm	- Centimeter
c c	- Cubic Centimetre
cu	- Cubic
dia	- diameter
F.C.	- Field capacity
Fig.	- Figure
gm	- Gram
hr.	- Hour
lit.	- Litre
max	- Maximum
$min^{\underline{m}}$	- Minimum
min	- Minute
m	- Meter
No.	- Number
Pw1	- Moisture content before irrigation
P_{w_2}	- Moisture content after irrigation
P_w	- Increament in moisture content
%	- Percentage
sec	- Second
sq	- Square
Vol	- Volume
wt.	- Weight

CHAPTER I

INTRODUCTION

INTRODUCTION

India is pre-dominantly an agricultural country an d most of its resources depend on the agricultural output. Water is evidently the most vital element in the plant life . India has unequal distribution and uncertainity of rainfall over the country, varying from 26 cm in North-West deserts of Rajsthan to about 1150 cm in the Assam hills. Substantial variations in the quality, incidence and duration of rainfall in individual tracts from year to year, make irrigation of supreme necessity in the country. Most of the rainfall is concentrated during a short period of about two and half months . It is therefore necessary to supplement the needs of growing crops with irrigation. In order to get maximum yield, it is essential to supply the optimum quantity of water and to maintain correct timing of water. This is possible only through a systematic irrigation system-by collecting water during the period of excess rainfall and to release it to the crop as and when it is needed. It is sad fact that in India huge quantity of irrigation water goes as waste through surface runoff and deep per colation because of improper methods of water application. Improvements in existing system of irrigation is, hence an important need of the day, to save the wastage of water.

Out of the total availabe area of 175 million-ha, in the country, an estimated 142 million-ha were under cultivation

by the end of Fourth plan year (1974). The gross cropped area was 169 millian-ha. The ultimate irrigation potential of the country was 107 million-ha, by the end of Fifth plan year about 57.9 millianha have been used. The water budget of India shows a utilizable quantity of water resources nearly equal to 105 millian-ha-m. So it is necessary to develop an efficient irrigation system in order to increase the food production, so as to meet ever increasing food demands. The proportion of irrigated area can be increased either by development of irrigation system or by increasing application efficiency.

"Irrigation in many country is an age old art, as old as civilization, but for the whole world, it is a modern science,- the science of survival." Water being a limited resource, its efficient use is basic to the survival of the ever increasing population of the world. It is a very precious resource, so no man has the right to waste water which another man needs. Experienced and good formers throughout the world believe that " The more water, the better for almost all the crops." After thorough examination of this conception it seems that its origin is in the usually low efficiency of water application.

In comand areas, there has always been great disparities in the demand and s upply of water because of its miserably low project efficiencies. On the otherhand excess water application results in nutrient removal by leaching, development of conditions fabourable for plant diseases, salt

accumulation and excess water in contact with the plant or its roots. Remedies for water lagging are usually expensive and frequently some of these lands are never truely productive again. Therefore, every effort must be made to use water most efficiently, so as to make possible a high level of continuous production and enhance command area efficiency.

The first irrigation commission (1901-1903) was appointed which submitted its report in the year 1903. Numerous multi purpose projects were planned and implemented during this period and are playing a great role in the over all prosperity of India. The second irrigation commission (1969-1972) was even appointed which submitted its report in March 1972.

Many design procedures for di ferent surface irrigation methods has been established in order to improve irrigation efficiencies. But no one of these techniques is used on former field, except for the research stations, since these are too complicated and are the beyond the reach of majority of illitrate formers.

Surface irrigation method is commonly used in our country for crop production. Generally Border method is used in most part of our country because of its suitability to all close growing crops like wheat, barley and fodder crops and legumes and to soils having moderately low to moderately high infiltration rate.

To carry out the experiment, borders were selected in the field, in which wheat crop was already being shown and all observations were taken during the second and third irrigations after sowing. At the time of second irrigation the crops was in the stage of growth (flowering stage) and during the third irrigation crop was in milky stage of growth.

The objectives of this study are :

1. To evaluate how efficiently the available water supply is being used under the existing conditions by measuring water application, water storage and water distribution efficiencies.
2. To study the soil parameters such as infiltration characteristics, field capacity and bulk density of soil which govern the pattern of flowin the borders during irrigation.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Efficient application of water to the field using different irrigation methods has always creates approblem for the irrigation engineers. To find out the irrigation effieiencies many investigators and researchers have approached different irrigation systems using varied irrigation amnagement techniques, which is reviewed and given below.

Israelson (1939) explained the fundamental concept of efficiencies. According to him, efficiency vary from locality to locality. They are influenced by cost and quality of labour, case of handling water crops being irrigated and soil characteristics. For these reasons irrigation efficiency is a broad general term, which can be applied to irrigation practices in qualitative manner.

He defined the term "water application efficiency" as the ratio of water stored in the soil in one irrigation to the volume delievered to the field.

He considered three important phases of measuring water application efficiencies as follows -

1. To provide an appropriate water, management structure for the farm.
2. To provide reasonally constant flow during the period of delivery to the field.

3. To provide the measurement of the amount of water that is stored in the root zone.

In (1937-1950) Parker & Israelson assuming a constant rate of infiltration and uniform depth of flowing water proposed a differential equation for flow in border irrigation which is expressed as below.

Q = Rate of inflow.

Y = Constant depth of flow

I = Constant rate of infiltration

A = Area of strip covered during any time, t.

During a differential time dt after t let water cover an additional area of dA, Then during dt

Total water supplied = Qdt (1)

Water absorbed by the soil = Idt (A + dA) (2)

Water added to surface storage= YdA (3)

By volume balance -

$$Q = Idt\ (A + dA) + YdA$$

neglecting the product of twodifferential and separating the variables -

$$\frac{YdA}{(Y-IA)} = dt \qquad (4)$$

Intergrating above equation within limits of t & 0.

$$Y \int_0^A \frac{dA}{(Q - IA)} = \int_0^t dt$$

or $$\frac{Y}{I} \log e \; (Q - IA) \Big|_{0}^{A} = (t)\Big|_{0}^{t}$$

or $$t = Y/I \log_e \frac{Q}{Q-IA}$$

In the above equation the rate of infiltration I and depth of flow have been assumed constant throughout the period of irrigation and length of run, which is practically not possible. However the equation gives the values for from the observed data.

Fuhriman (1951) gave the measurement of water application efficiency of irrigation and proposed a new formula to calculate this as given below.

$$Ea = \frac{(pw_2 - p_{w1}) \; As \times D}{100} + Va + Vb/ \; \frac{Qt}{A} + r \times 100$$

In which,

Ea - Water application efficiency in %.

A - Area of field in acres.

As - Average apparent sp. gr. of soil in root zone.

D - Depth of root zone in inches.

P_{w_1} - Moisture percentage in root zone before irrigation dry wt. basis.

Q - Discharge of irrigation stream in cu.ft/sec.

P_{w2} - Moisture percentage in root zone after irrigation, dry wt. basis.

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r - Rainfall between samples P_{w_1} and P_{w2} in inches.

t - Time required to irrigate field in hours.

Va - Consumptive use of water in period P_{w_1} & time of water is applied.

Vb - Consumptive use of water in the interval

between the beginning of irrigation and the time p_{w_2} sample taken in inches.

He emphasized that the errors caused by neglecting the consumptive use factor in water application effiei-ency measurements are very large in some cases.

G.S. Decker (1953) found out the application of the soil moisture characteristics curve and said that curve will enable an irrigation to apply the water more effic-iently. He found the presence of moisture that is willing range from these two values. The amount of moisture avail-able in the soil can be required. The curve is plotted by volume obtaining by making test with the pressure and memberane apparatus and is used in other studies of the soil and i s moisture system.

$$Es = (1 - \sum_{I}^{n} ai\ ei/A)\ 100$$

where,

Es = The water storage efficiency

A = The total area of the irrigated field.

ai = Area of the field receiving a deficient irrigation.

(e_1, e_2 ....& i.......e_n) = the ratio of moisture defieiency oin the root zone of the soil following the irrigation to the moisture deficiency prior to the irriga-tion on areas a_1, a_2.......a_i......a_n respectively.

His foresight study and looking gave a definite rather distinct pattern of water storage efficiency. The area involved could be determined in the field by facing and the extent of the moisture efficiency with soil auger

and chart, relating the appearance and fed to approximate soil moisture.

He knowledged further and emphasized that the major weaknesses in the irrigation practice can be quantitatively evaluated by use of water storage efficiency concept .

Criddle, Davis, Pair and Schockley (1956) gave methods for evaluating irrigation systems. According to them unit streams must be empirically adjusted for the expected level of field application efficiency. The general formula for the computation of unit stream for any given soil is-

$$Q = \frac{1 \ (T) \quad F}{E \ (T-T_1) \ 7.2 \ T} \qquad (1)$$

Where

Q = Unit streams in cu.ft/sec.

E = Efficiency expressed as a decimal.

F = Desired depth of water application in inches.

T= Time, in min required for the infiltration of F inches of water.

T_1 = Recession time log in min. (from the time the stream is cut off until recession begins).

The time (T) in hrs. can be computed from the formula

$$T = \frac{d}{432.E.Q} \qquad (2)$$

Where

d= Required net depth of application in inches.

E = Expected efficiency level.

Q = Design unit streams in cu. ft/sec.

The criteria used to define the minimum unit stream fro

graded border irrigation is as follows.

$$Q_{(min)} = 0.0045^{0.5} \qquad (3)$$

Where
S = Irrigation slope in percent.

Jashwant Singh (1959-60) has defined a formula for the percolation loss for any width as below.

$$Ip = \frac{(m+1)^{1+b} - (m)^{1+b}}{(m-1)^{1+b} + (m)^{1+b}} \times 100$$

Where,

Ip = Percent percolation loss

m = t_1/t_2

t_1 = time required for the water front to reach upto the end at root zone.

t_2 = Time required for the moving water sheet to reach the end of run.

b = A dimension less constant.

Hanson (1960) proposed the following relationship.

$$Ea = \frac{w_s}{w_f} \times 100 \qquad (1)$$

Where,
Ea = Water application efficiency.

w_s = Water stored in the root zone during the irrigation.

w_f = Water delivered to the farm.

$$Ed = (1 - \frac{Y}{d}) \times 100 \qquad (2)$$

Where,
Ed = Water distribution efficiency.

Y = Average numerical deviation in depth of water, stored from average depth stored furing irrigation.

d = Average depth of stord during the irrigation.

Shocklay Etal. (1966) considered the following phenomenonan designing the grade broder -

1. The intake characteristics of the soil.
2. The rate of advance of water from moving down the border strip.
3. The rate of recession of water from the border strip after the irrigation stream has been turned off.

He has tried to adjust the size of the irrigation stream to the in take characteristic of the soil. The slope of the border strips and the area to be curved, so as to provide a nearly uniform time of water coverage at all points along the length of border strips. He has given the two following equations maximum length of border.

$$L_{max} = 1.2 \times 10^{10} \frac{E}{Fn} T^6 \left(\frac{1.486}{n}\right) 6_S{}^8$$

Where,

L_{max} = max length of border strip in ft.

E = Field efficiency in %.

F_n = Net irrigation application in inches.

T = Required opportunity time for infiltration of funiminate.

n = Manning's constant.

S = Slope in ft.

Fok and Bishop (1969) has given a formula for calculating the application efficiency, which is as follows -

$$Ea = \frac{(n+2)R^{(n+1)}}{F\ (R+1)^{b+n+1}} \times 100$$

Where,

Ea = Application efficiency in %

$R = t_2/(t_1 - t_2)$

$(t_1 - t_2)$ = Time required for the water to reach the end of border.

F = Correction factor

$$F = b(n+2) + \frac{1}{b} - \frac{n+1}{b+1} + \frac{(n+1)^n}{2(b+2)}$$

n = empirical const. of intake rate.

b = Explained of empirical water advance.

$b = e^{-0.1b(n+1)}$

This equation gives the expression of the application efficiency in the term of n, b, F & R.

Mūrti and Verma (1978) obtained an expression for the percolation losses and hence the application efficiency. The formula put forth by them to calculate percolation losses is as follows.

Percolation losses

$$\frac{ST + AT - \left(\frac{B}{B+1}\right) + L\left(H + \frac{S}{2T}\right) - (Std + Atd)}{ST + AT - \left(\frac{B}{B+1}\right) + L\left(A + \frac{S}{2T}\right)}$$

in which, S And A = Cost in Philips infiltration.

eg. $(= st^{1.2} + At)$

T = Time by which recession is complete.

B = Const. of the advance function

tL = Time to advance the total length

td = Time to infiltrate depth.

Once the percolation losses are known. The application efficiency can be calculated further they proposed a formuls to calculate application efficiency as-

$$Ea = \frac{td^{n+1}}{T^{n} + 1} \times 100$$

Where,

Ea = Water application efficiency.

n = Const. in Kostiakov's infiltration.

B.D. Adkine (1979), conducted and experiment to evaluate the application and distribution efficiency in border and check basis irrigation methods and from his experiment he concluded following results.

(1) The application efficiency and distribution efficiency increases with the increase in discharge rate for a constant area.

2. The efficiency are found to be higher for all size-checks and all discharge rates in the vegetated check basin as compared to vegetated borders.

3. No effect of efficiencies was found on the yield of wheat within the given set of conditions.

4. The optimum rate of discharge for higher efficiencies has been found to be within the range of 0.0666lit/sec/m^2 to 0.1 lit/sec./unit area (m^2).

CHAPTER III

THEORETICAL CONSIDERATION

THEORETICAL CONSIDERATION

BORDER IRRIGATION :

The border method of irrigation makes use of parallel ridges to guide a sheet of flowing water as it moves down to slope. The land is divided into a number of long parallel strips called borders that are separated by low ridges.

TYPES OF BORDERS : There are three types of borders :

1. LEVEL BORDERS : This is a ponding method of water application. Border strips have no slope in the direction of flow and they are closed at ends. The water is retained in the field until infiltratesin to the soil.

2. GRADED BORDER : This is a balanced advance recession method of irrigation. Borders are laid along the general slope of the field (graded or down the slope borders) and ends are not usually closed. But there is no slope across the strip. Thewater stream is turned in at the upper end and as the water front approaches the lower end of the strip, the stream is turned off. When fields can be levelled to desirable lands slopes economically and without affecting its productivity, graded borders are easier to construct and operate.

3. CONTOUR BORDER : When land slope exceeds the safe limits, fields are undulating and levelling is not feasible,

the borders may be laid across the slope and are called, contour borders. Each contour border is level cross wise and has a uniform longitudinal gradiant as in graded borders.

BORDER SPECIFICATIONS AND STREAM SIZE :

In evaluating border irrigation systems, the basic Variables ifluuencing the hydraulics of slow in borders are determined, and the characteristics of flow measured.

WIDTH OF BORDER STRIP :

The width of border strip usually varies from 3 to 15 meters, depending upon the size of irrigation stream available and the degree of land levelling practicable. When the size of irrigation stream is small, the width is reduced. It is, however, not economical to keep the width less than 3 meters, as otherwise, too many ridges will have to be formed per unit area of the land suffface.

BORDER LENGTH :

The length of border strip depends upon how quickly it can be wetted uniformly over its entire length. This in turns depends on the infiltration rate of the soil, the scope of the land, and the size of irrigation stream available. For moderate slopes and small to moderate size irrigation stream. The following border lengths are suggested-

Sandy & sandy loam soils	- 50 to 120 metre
Medium loam soils	-100 to 180 metre
Clay loam & clay soils	-150 to 300 metres.

BORDER SLOPE :

The border should have a uniform longitudinal gradient slope. Excessive slopes will make the water run to the lower and quickly, causing insufficient irrigation at the up-stream and deep percolation losses and breach the bund at the down stream. They also cause soil erosion in borders. On the other hand, too flat slopes will result in the very slow movement of the border stream, causing deep percolation losses at the upper reaches and inadequate wetting down stream. Eecommended safe limits of land slopes in borders are given as-

Sandy loam to sandy soils	-	0.24% to 0.6%
Medium loam soils	-	0.20% to 0.40%
Clay to clay loam soils	-	0.05% to 0.2%

SIZE OF IRRIGATION STREAM :

The size of stream needed depends on the infiltration rate of the soil and width of border strip. Course textured soils with high infiltration rates require large streams to spread water over the entire strip rapidly and avoid excessive losses due to deep percolation at the upper reaches. Fine textured soils with low infiltration rates require smaller streams to avoid excessive loss due to run off at the down stream end and deep percolation at the lower reaches.

ANALYSIS OF TIME TO COVER A STRIP :

Size of irrigation stream applied to unit area of land be varied according to rate of infiltration of water into the soil. The relationship between size of stream and time of rate of water application over a given area of land can be most easily stated by means of rational equation.

$$t = 2.303 \frac{Y}{I} \log 10\ q/(q-IA)$$

The constant of integration being zero since A=0 when t=0.

In the avove equation, I has considered constant, but actually I decreases as soil gets saturated and the above equation can be re-written.

$$\log 10 \quad \frac{q}{q-IA} \equiv \frac{It}{2.303y} = x \text{ (say)}$$

or

$$10^x = \frac{q}{q-IA}$$

from which,

$$A = \frac{(10^x-1)q}{10^x.I} = q/I$$

This equation is very important since it gives the maximum area that can be irrigated with a stream of discharge q.

IRRIGATION EFFICIENCY :

In general, efficiency is the ratio of the water out put tp the water input and is expressed as percentage. Irrigation efficiency indicates how efficiently the available water supply is being used, based on different methods of evaluation. The design of irrigation system, the degree of land preparation, and the skill and care of irrigator are the principal factors influencing irrigation efficiency, loss of water occurs in the conveyance and distribution system, non-

uniform distribution of water over the field, percolation below crop root zone, and with sprinkler irrigation evaporation from thesprayn and retention of water on the foliage. In case of large fields loss may occur by run-off at the end of irrigation borders and furrows. The losses can be held to a minimum by adequated planning of the irrigation system, proper design of irrigation method, adequate land preparation of irrigation method, adequate land preparation and efficient operation of system.

(1) WATER CONVEYANCE EFFICIENCY :

This takes into account the conveyance or transite losses and is determined from the following expression:

$$E_c = \frac{W_f}{W_r} \times 100$$

Where

E_c = water conveyance efficiency.

W_f = Water delivered to the irrigated plot.

W_r = Water supplied at the source.

(2) WATER APPLICATION EFFICIENCY :

The following concept of water application efficiency was developed to measure and focus attention upon the efficiency with which water delivered was being stored within the root zone of the soil, where it could be used by plants. Mathematically it is expressed as :

$$E_a = \frac{W_s}{W_f} \times 100$$

Where,

E_a = Water application efficiency.

W_s = Water stored in the root zone during

the irrigation.

W_f = Water delivered to the plot.

The common sources of loss of irrigation water during application are :

(i) Surface runoff (R_f) from the form and

(ii) Deep percolation (D_f) below the form root zone soil.

Hence

$$W_f = W_s + D_f + R_f$$

$$E_a = \frac{W_f - (R_f + D_f)}{W_f} \times 100$$

(3) WATER STORAGE EFFICIENCY :

This concept directs attention to how completely the needed water has been stored in the root zone during the irrigation. It is defined as-

$$E_s = \frac{W_s}{W_n} \times 100$$

Where,

E_s = water storage efficiency.

W_s = Water stored in root zone during irrigation.

W_n = Water needed in the root zone prior to irrigation.

(4) WATER DISTRIBUTION EFFICIENCY :

This evaluates the degree to which water is uniformely distributed throughout the root zone. This efficiency provides a measure for comparing various systems or methods of water applications. It is defind as :

$$Ed = 100\ (1 - Y/d)$$

in which,

E_d = Water distribution efficiency

Y = Average numerical deviation in depth of water stored from average depth stored during irrigation.

d = Average depth pf water stored during irrigation.

(5) WATER USE EFFIENCY :

The water utilization by the crop is generally described in terms of water use efficiency (kg/ha-cm or q/ha-cm. It can be defined in the following wasy.

(i) CROP WATER USE EFFIECENCY : It is definded as :

$$\text{Water use efficiency} = \frac{Y}{E_T}$$

Where,

Y = Crop yield per unit area.

E_T = The amount of water depleated by the crop in the process of evapo-transpiration per unit area.

(ii) FIELD WATER EFFIENCY :

It is definded as :

$$\text{Field water use efficiency} = \frac{Y}{WR}$$

Where,

Y = crop yield per unit area.

WR = total amount of water use in the field per unit area.

EVAPORATION :

Evaporation is the process during which a liquid changes into a gas. The process of evaporation of water in nature is one of the fundamental components of the hydrological cycle by which water changes to vapour through the absorption of heat energy.

TRANSPIRATION :

Transpiration is the processes by which plants dissipate water from the surface of their leaves, stalks and trunks in the process of growth.

CONSUMPTIVE USE OF WATER (EVAPO-TRANSPIRATION):

Evapo-transpiration or consumptive use of water by a crop is the depth of water consumed by evaporation and transpiration during crop growth, including water consumed by accompanying weed growth. Water deposited by dew or rainfall, and subsequently evaporating without entering the plant system is part of consumptive use.

INFILTRATION :

Infiltration is the downward entery water into the soil.

INFILTRATION RATE :

It is the soil characteristic determining the maximum rate at which water can enter the soil under specified conditions, including presence of excess water. It has dimensions of velocity. The actual rate at which water is entering the soil at any given time is termed the infiltration valacity.

BASIC INFILTRATION :

The rate at which water will enter the soil after a period of several hours when the change in infiltration rate becomes very slow.

ACCUMULATED INFILTRATION :

It is the total quantity of water that enters the soil

in a ginen time. Infiltration rate and accumulated infiltration are the two parameters commonly used in evaluating the infiltration characteristics of soil.

$$\text{Accumulated infiltration (depth)} = \frac{\text{Accumulated infiltration (Vol)}}{\text{Wetted area of test section.}}$$

For design purposes, the relationship between accu. infiltration and elapsed time are usually expressed by the following Kostiokov's formula :

$$I = kt^n \qquad (1)$$

Where,

I = Infiltration rate

t = elapsed time

k and n are constants.

$k \quad 0$ and $0 \quad n \quad -1$

After integrating the above equn. within limits of t and 0

Thus $\int_0^t I\,dt = \int_0^t kt^n$ or $y = \frac{Kt^{n+1}}{n+1}$

or $y = at^b$ where a and b are new const.

$a \quad 0$ and $0 \quad b \quad 1$

Kostiakov's formula does not fit well for large value of t. It is most commonly adopted equn. due to the simplicity, to represent infeltration when t is small.

SEEPAGE :

Seepage is the infiltration (vertically) downward and lateral movement of water into soil. Seepage rate depends on the wetted parameter of the reservoir or the canal and the capacity of the soil to conduct water both vertically and

laterally.

EFFECTIVE ROOF ZONE :

Effective root zone is the depth from which the roots of an average mature plants are capable of reducing soil moisture to the extent that it should be replaced by irrigation. Root zone depth varied with the type of soil and nature of plant root development.

FIELD CAPACITY :

The field capacity of the soil is the moisture content after drainage of gravitational water has become very slow and moisture content has become relatively stable. When irrigation is done the amount of water supplied should be such that water content is equal to the field capacity.

MOISTURE - CONTENT :

The amount of moisture that is held by a certain mass on volume of soil can be expressed as weight percent pr volume percent. Soil moisture is being defined in following ways:

(i) Soil moisture content in percentage $(pw)_{w.b.}$ (based on wet wt. basis)

$$= \frac{\text{Amount of water present in the soil sample (Ww)}}{\text{Wet wt. of soil sample (W)}} \times 100$$

(ii) Soil moisture content in percentage (pw)d.b. (on dry weit. basis)

$$= \frac{\text{Amount of water present in the soil sample } (W_w)}{\text{dry wt. of soil sample } (W_d)} \times 100$$

DEPTH OF WATER STORED IN THE ROOT ZONE :

$$d = \frac{p_w * A_s . D}{100}$$

Where, d= depth of water stored in the root zone.

p_w= % increment in soil moisture after irrigation.

A_s= Apparent Sp. gr.of soil

D= Root zone depth (Generally taken equal to 90 cm)

BULK DENSITY :

The bulk density is defined as the total wt. W of a soil mass per unit of its total volume V.

Thus $$r = \frac{W}{V}$$

Where r = Bulk density in gms/cc

$$\text{Dry bulk density } (r_d) = \frac{\text{Dry wt. of soil sample(Wd)}}{\text{Total volume (V)}} \text{gms/cc}$$

SPECIFIC GRAVITY AND APPARENT SPECIFIC GRAVITY :

Specific gravity is defined as the ratio of the wt. of a given volume of soil solids at a given temperature to the weight of an equal volume of distilled water at that temperature, both weights being taken in air. In other words, it is the ratio of unit weight of soil solids to that of water .

$$G = \frac{r_s}{r_w}$$

Where G - sp.gr.

r_s - density of soil solids.

r_w - density of water

It is a dimension less quantity.

The apparent specific gravity of a soil is defined as the ratio of the wt. of a given volume of dry soil, air space included, to the wt. of an equal volume of water. This ratio is known as the "Volume weight" or bulk density.

Apparent sp.gr. of soil = $As = \frac{r}{1+p_w}$

Where r = Bulk density.

p_w = Existing moiture content in fraction.

C H A P T E R IV

MATERIALS AND METHODS

MATERIALS AND METHODS

SURVEY OF THE BORDER SYSTEM OF IRRIGATION :

A survey of A.A.I. farm was conducted to study the existing practices of border system of irrigation. The size of the borders were measured with the help of measuring tape (metallic tape, 30 m long) for the adoption of methods and reasons for practising particular size of borders.

SELECTION OF SITE :

Agronomy Research plot was selected for these experiments because of its almost levelled land and better irrigation and other facilities. This plot receives its water supply from tubewell no.7. Adequate water control facilities like regulating valve and distribution chember are also available at the site. The supply channel is aligned on the upper side of the plot. R.R.21 variety of wheat was already sown and crop was in flowering stage of its growth during first irrigation and in the milky stage during the second irrigation observations.

The experiments were conducted on cropped area. The general layout of the experimental plot was in such away as shown in(figure -I)

LAYOUT :

In the experiment three borders of sizes 30mx5.15m, 30mx4.38m and 30.5x4.95m respectively were selected from the existing area. Two discharge rates were applied to each area units. Some discharge rates were maintained during

all irrigations to particular borders.

The essential feature of border irrigation is to provide on even surface over which water can flow down the slope with a uniform depth. Each strip is irrigated independently by turning in a stream of water at the upper end. The observations were started after first irrigation after sowing and were continued till the last irrigation before hervesting.

EQUIPMENTS USED AND THEIR DESCRIPTIONS

(i) CYLINDER TYPE INFILTROMETER :

Concentric double cylinder infiltrometer were used for determination of infiltration characteristics of the experimental fields. Three same sizes of double cylinder infiltrometers were used in three different places in the three borders. The inner cylinders from which the actual in-filtration measure-ments are made, were 29.5 cm dia and 35.5 cm high. The outer or guard cylinders were of 40 cm dia and 35.5 cm high. The cylinders were made of 10 gauge mild steel sheet and the lower edges were sharpened as so to facilitate easy penetration into the soil. Point gauge was used measure the water level in the cylinder.

(ii) DRIVING UNIT :

A square mild Steel plate of 60 x 60 x 0.7 cm size with a galvanized iron pipe 3.2 cm. dia, welded at centre of the plate was used to distribute the impact of hammer uniformly to the entire edge of the cylinders. A hammer which could

slide on the vertical G.I. pipe was used to drive the cylinders into the soil.

(iii) SOIL AUGER OR SOIL SAMPLER :

Soil sampling auger is used to determine the soil moisture. A spiral shaped bit made from hardened steel of carpenters auger type is used to take the soil sampls. Samples were collected at several spots in 30 cm depth increment upto a total depth 90 cm. This auger performed well as there was enough moisture for its functioning.

(iv) DRYING OVEN :

220 volt, single phase, 60 cycles, A.C. 1750 watt oven was used for drying the soil samples. The temperature range of the oven $50^{o}c$ to $300^{o}c$. The soil samples were placed on the oven for 24 hours at a temperature of $105^{o}c$ so that the soil organic matter does not decompose.

(v) HOOK POINT GAUGE :

It is used for the measurement of head of water in the orifice and to measure the water level in the cylinder infiltrometer and to measure the depth of sheet of water flowing over the surface in the borders.

(vi) SUBMERGED ORIFICE PLATEMETER :

Submerged orifice platemeter was used to measure the discharge. The meter was made of 3mm. thick (10 gauge) m.s. plate bulk head. The size of plate was 60cmx50cm with a

5.4 cm dia hole at centre. The meter was installed in the supply channel near the inlet end of borders.

The discharge through the orifice meter was calculated by using the formula.

$Q = 0.64 \times 10^{-3}\ a\ \sqrt{2gH}$ lit/sec.

in which,

Q = discharge through orifice lit/sec.

a = area of cross-section of the orifice (sq.cm.)

g = acceleration due to gravity (cm/sec^2, $981 cm/sec^2$

H = difference in elevation between the water surface at the upstream and the down-stream faces of the orifice plate in cm.

(vii) SAND CONE APPARATUS :

The apparatus consists of (i) Sand pouring cylinder of about 3 litre capacity, mounted above a pouring cone and separated by a shutter cover plate and a shutter. (ii) Cylindrical calibrating container, 10 cm internal dia and 15 cm internal depth fitted with flange approximately 5 cm vide and about 5 mm thick. (iii) Metal tray with a central circular hole of diameter equal to the dia of pouring cone. (iv) Tools for excavating hole (v) Balance and clean, closely graded natural sand passing the 600-micron I.S. sieve and retained on the 300-micron I.S. sieve.

METHOD OR PROCEDURE :

1. STREAM SIZE CONTROL :

The size of stream was controlled by giving definite no. of turning to the wheeal of regulating value at the tube-well end and also allowing over flow at pre-fixed heights in the

distribution chamber which were located at the head end of the field. Till the desired difference in d/s and u/s head was obtained at the orifice meter, the water was allowed to flow in waste channels

2. DETERMINATION OF MOISTURE CONTENT :

The soil sampling spots are shown in figure of general layout offthe experiments. At each spot samples were collected for 0-30 cm, 30-60cm, 60-90cm depth. The samples after collecting from the field in the aluminium box was taken to the laboratory and moisture content was found by gravimetric method using physical balance for weighing. Hot air oven was adjusted to a constant temperature of 105^{o}c for drying of the samples. Moisture on dry wt. basis was calculated.

Moisture reading from replicated plots were averaged and overall moisture contents for different time periods were tabulated. From the initial moisture contents and the moisture after 24 hrs. in different depth zones, the depth of water penetration was found.

3. DETERMINATION OF FIELD CAPACITY :

First of all suitable places were located amd rempved the weeds, then 90 cm. length, 90cm. width and 30 cm. depth a pit was due and the water was filled in this upto a depth of 15 to 20 cm. Then after filling of water soil samples were taken at each successive interval of 10 hours. Thus about 6 times soil samples were taken qt the depth of 30cm.,

60 cm., 90cm. respectively. Then the mlisture content of the soil were found out of each soil sample. Care should be taken that water should not be evaporated. The constant and lowest reading can be taken to represent the value of field capacity of the soil.

4. MEASUREMENT OF INFILTRATION :

Infiltration characteristices of the field were obtained by double cylinder infiltrometer. The cylinders were drown into the ground by putting the driving plate over the cylinders and dropping the hammer on the plate until cylinders penetrates 12 to 15 cm. The water level in the inner cylinder was read by using point gauge. The water was added in the inner cylinder from a container of known volume (measuring cylinder). It was added by pouring on to a piece of polythene. The polythene was used to prevent puddling and sealing of surface soil. After filling the cylinder to about 3/4 of the desired level the polythene sheet was removed.

A stop watch was used to note the instant of addition of water began and the time the water reached the desired level. The total quantity of water added to the inner cylinder by determined by the measuring cylinder. The difference between the quantity of water added and volume of water in the cylinder at the instant it reached during the time interval between the start of filling and first measurement. The water was added quickly after each measurement so that constant infiltration head could be maintained. The buffer

pond was filled with water immediately after filling the inner cylinder. The water level in the inner cylinder and buffer pond were kept opproximately the same. The experiment was continued beyond the estimated time the water would stand in the basic during irrigation. The data were tabulated on a standard form as shown in tables (A_3).

5. DETERMINATION OF BULK DENSITY:(APPARENT SPECIFIC GRAVITY)

First of all we selected the different places in the different borders and removed the grass and weeds etc of about 45 sq. cm area of soil at each place and surface was made level. After that we kept the tray on level suface and a circular hole of approximately 10cm dia and 30cm deep was excavated and all excavated soil in the tray was being collected. Then soil was kept in polythene bags and weighed in the laboratory. After that we placed the sand pouring cylinder over the tray, so that base of the cylinder concentrically coveres the hole. The sand pouring cylinder was filled with clean closely,graded sand in the upto height 1 cm below the top and then opened the shutter and permitted the sand to run into the hole. When no further movement of sand was seen the shutter was closed and noted down the height of sand column standing in the pouring cylinder. By detecting the volume of cone of cylinder, we found the volume of sand required to fill the hole. After that we repeated the experiment at different places and at different depths. Excavated soil was collected at each time in polythene bags and weighed

in the laboratory. Then Bulk density of soil was found by deviding the wt. of soil by the volume of sand required to fill the hole.

In order to find the bulk density on dry wt. basis, moisture contents were determined by gravi metric method.

6. EFFICIENCY CALCULATION :

The water application efficiency and water storage efficiency and distribution efficiency after irrigation in cropped land were calculated as follows.

(i) $$E_a = \frac{W_s}{W_f} \times 100$$

Where

E_a = Water application efficiency in %

W_s = Water stored in root zone during the irrigation including the amount of water utilized by plants (Evapotranspiration) in 48 hrs.

W_f = Water delivered to the filled.

W_s is being obtained as under :

W_s =(average depth of water stored + Evapotranspiration)x Area m^3.

and

$$d = \frac{P_w . A_s . D}{100} \text{ cm}$$

(ii) WATER STORAGE EFFICIENCY :

$$E_s = \frac{W_s}{W_n} \times 100$$

Where E_s = Water storage efficiency in %

W_s = Water stored in rootzone during the irrigation including the amount of water utilized by plants(EVapotranspiration) in 48 hrs.

W_n = Water needed in the rootzone prior to irrigation.

$$W_n = d_1 \times Area.m^3$$

$$d_1 = \frac{P_{w_1} \cdot A_s \times D}{100} \text{ cm}$$

Where P_{w1} = (Field capacity - available moisture).

A_s = Apparent specific gr.

D =(Depth of rootzone in cm.) being considered 90 cm.

The volume of water applied to the plot was calculated by multiplying the discharge rate and total time required for filling the plot.

(iii) WATER DISTRIBUTION EFFICIENCY :

The distribution efficiency for different borders is being calculated by using the following expression :

$$E_d = \left(1 - \frac{y}{d} \right) \times 100$$

Where d = Average depth of water stored along the run during the irrigation.

y = Average numerical deviation from d.

To consider the crop factor in calculating efficiencies, I have taken values of consumptive use for wheat crop during the period of Jan. to April 1978.The values of consumptive use are being considered 2 mm/day during first irrigation observation when crop was in flowering stage (nearly 60 days old) and 3 mm/day during second irrigation observation when crop was nearly 80 days old (in milky stage) based on the experiment conducted by Thomas K.John,(1978).

CHAPTER V

RESULTS & DISCUSSION

RESULTS AND DISCUSSION

The experiments were conducted at Agronomy research plot of A.A.I. form, to evaluate the irrigation efficiencies foo the existing border irrigation system for wheat crop and to study soil parameters such as field capacity, infiltration characteristics and bulk density of soil which govern the pattern of flow. The soil of the field was sandy loam and experiments were conducted in month of Feb.-March 1983, when crop was in flowering stage and milky stage.

The experimental set up was made to study the infiltration characteristics by double cylinder infiltrometer. The values of constants a and b were found to be 0.59 and 0.44 respectively. The plots of accumulated infiltration (y) and computed (y) against elapsed time (t) are being shown in Fig. III which indicate that for smaller values of t the equation $y = 0.59\ t^{0.44}$ holds good since for smaller values of t, the deviations between observed values and calculated values are not much. But for higher values of t the relationship does not hold good as indicated by figure III.

The plot of y against t is shown on log-log paper in figure IV. The obtained plot is a straight line which satisfies the equation $y = 0.59\ t^{0.44}$.

The bulk density of soil was found to be 1.58 gms/cc to ensure depth of water needed to fill or stone upto rootzone depth.

The field capacity of soil was estimated 22.5% as shown in Fig. II.

In order to determine the amount of water needed to fill the root zone at field capacity, moisture contents were found by taking soil samples before and after the irrigation.

The rootzone depth for wheat crop was estimated 90 cm.

Three borders of sizes 30mx5.15m. , 30m,X4.38m and 30.5m X 4.95m were selected and two discharges 2.4 lit/sec. and 2.91 lit/sec. were taken for the experiment. The discharge rates were measured by using submerged orifice plate a meter and were kept constent during the irrigations.

The water application efficiency estimated to be 85 .5%, 83.28% and 91.90% during the first irrigation and 91.10% , 94.92% and 87.13% during second irrigation for three borders respectively and water storage efficiency estimated 80.35%, 68.32% and 80.60% during first irrigation and 78.95%, 73.19% and 77.20% during the second irrigation for three borders respectively.

Higher water storage efficiency can be obtained if excess amount of water is being applied during each irrigation, to fill the rootzone upto, field capacity which results in in low water application efficiency, since excess water application country contributes to losses such as, deep percolation and seepage losses.

The water application efficiency can be achieved 100% by if insufficient amount of water is being applied which contributes to low water storage efficiency.

Thewater distribution efficiency estimated 91.15%, 53.125% and 81.96% during first irrigation and 92.02%, 87.77% and 83.69% during second irrigation for three borders respectively as indicated in table B_4. The obtained value of distribution efficiency indicates uniform distributions of water into the field rootzone.

C H A P T E R VI

CONCLUSION

CONCLUSION

In order to determine the application of water, soil parameters such as infiltration characteristics, field capacity and bulk density were determined in all the three selected borders separately. Similarly water application, stroge and distribution efficiencies were estimated in order to ascertain the exact amount of water to be diverted from the source, in order to fulfil irrigation requirements.

The results indicated water application efficiency 88.97%, storage efficiency 76.88% and distribution efficiency 81.63% under given conditions. Bulk density and field capacity were estimated 1.58 gms/cc and 22.5% respectively. The values of the constants a and b in infiltration equation ($y = at^b$) were estimated as 0.59 and 0.44 respectively. On the basis of results obtained during the experiments, following ideas were concluded:

The infiltration equation $y = 0.59t^{0.44}$ holds good for smaller values of elapsed time (t). The obtained values of irrigation efficiencies indicate appropriate size of borders, proper land topography, uniform bed of the field and available water supply is being used efficiently. The values of water application and distribution efficiencies are higher than storage efficiency which endicate that field was not irrigated upto field capacity.

C H A P T E R VII

SUGGESTIONS

S U G G E S T I O N S

1. This experiment does not give the clear ideas for large areas and at varying discharges, so the experiment should be conducted for large sizes of border under varying discharge conditions.

2. Experiment should be also carried out on varying conditions of soils such as at different slopes and under different land topography.

3. To get precise estimation of infiltration characteristics of soil of experimental plots, infiltration tests should be carried out under different soil moisture conditions.

CHAPTER VIII

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A P P E N D I X

APPENDIX A

TABLE A_1

BULK DENSITY OF SOIL OF EXPERIMENTAL PLOT

S. No.	Depth of soil in cm	wt. of soil in gms	Vol. of soil in cc	Bulk density (r) of soil in gms/cc	wt. of sample box in gms	wt. of wet soil sample + sample box in gms	wt. of dry soil sample + sample box in gms	wt. of dry soil in gms	wt. of water in gms wt	Moisture content on dry wt.	Bulk density of soil $=\frac{r}{1+pw}$ gms/cc
1	2	3	4	5	6	7	8	9	10	11	12
1.	30	4600	2378.23	1.93	15.338	95.23	82.543	67.205	12.687	18.88	1.62
2.	60	5250	2898.79	1.81	16.430	98.235	84.335	67.905	13.900	20.47	1.50
3.	90	5375	3019.66	1.78	16.870	97.910	83.790	66.920	14 .120	21.10	1.47
4.	30	5800	3102.93	1.87	22.398	70.650	65.175	42.777	5.475	12.89	1.66
5.	60	5500	2868.17	1.91	17.730	77.260	69.280	51.550	7.980	15.48	1.65
6.	90	5750	2904.04	1.98	16.073	74.112	65.748	49.675	8.365	16.84	1.69
7.	30	4850	2674.24	1.81	17.170	102.59	90.280	73.110	12.310	16.80	1.55
8.	60	4850	2715.10	1.79	16.670	80.850	71.520	54.850	9.330	17.01	1.53
9.	90	4875	2678.57	1.82	15.250	79.045	69.350	54.100	9.695	17.92	1.54

Bulk density of soil (r) = 1.58gms/cc

TABLE A_2

FIELD CAPACITY OF SOIL OF EXPERIMENTAL PLOT.

S. No.	Depth in cm	Time in hrs	wt. of sample box in gms	wt. of soil sample with box in gms	wt. of dry soil sample with box in gms	wt. of dry soil in gms	wt. of water in gms	Moisture content %
1	2	3	4	5	6	7	8	9
1.	30	10	16.430	63.552	48.277	31.847	15.275	43.97
2.	-	20	17.005	51.785	42.605	25.600	9.180	35.86
3.	-	30	51.78	69.835	56.870	41.620	12.965	31.15
4.	-	40	15.975	62.235	52.145	36.170	10.090	27.89
5.	-	50	15.338	51.016	44.282	28.944	6.734	23.26
6.	-	60	16.930	61.475	53.175	36.245	8.300	22.90
1.	60	10	15.338	67.022	51.132	35.794	15.890	44.39
2.	-	20	16.277	66.273	50.753	34.476	15.520	36.32
3.	-	30	15.805	60.000	59.000	43.195	13.320	30.84
4.	-	40	16.835	73.920	61.365	44.530	12.555	28.17
5.	-	50	22.392	56.927	50.712	28.314	6. 215	21.95
6.	-	60	16.870	73.515	63.290	46.420	10.225	22.03
1.	90	10	17.170	111.96	84.275	67.105	27.685	41.25
2.	-	20	16.923	85.945	67.080	50.105	18.865	37.62
3.	-	30	21.505	93.133	76.330	54.825	16.803	30.65
4.	-	40	17.570	106.83	86.970	69.400	19.860	28.62
5.	-	50	22.392	81.740	70.690	48.248	11.050	22.85
6.	-	60	16.100	94.720	79.980	63.880	14.440	22.60

TABLE A_3

CUMULATIVE INFILTRATION AND RATE OF INFILTRATION AS A FUNCTION OF TIME.

S. No.	Time in min	Depth in cm	Accu. Infiltration in cm	Infiltration rate in cm/hr	Depth in cm	Accu. Infiltration in cm	Infiltration rate in cm/hr	Depth in cm	Accu. Infiltration in cm	Infiltration rate in cm/hr	Av. Infiltration rate cm/hr	Av. accu. Infiltration cm/hr
1	2	3	4	5	6	7	8	9	10	11	12	13
1.	5	1.06	1.06	12.72	1.10	1.10	13.2	1.33	1.33	15.96	13.96	1.16
2.	10	0.50	1.56	6.0	0.51	1.61	6.12	0.74	2.07	8. 88	7.0	1.75
3.	15	0.29	1.85	3.48	0.32	1.93	3.84	0.43	2.50	5.17	4.16	2.09
4.	25	0.42	2.27	2.52	0.44	2.37	2.64	0.35	2.85	2.11	2.42	2.50
5.	35	0.26	2.52	1.56	0.26	2.63	1. 56	0.27	3.12	1.62	1.58	2.75
6.	45	0.26	2.73	1.26	0.22	2.85	1.32	0.25	3.37	1.50	1.36	2.99
7.	60	0.18	2.91	0.72	0.20	3.05	0.80	0.20	3.57	0.81	0.77	3.18
8.	75	0.16	3.07	0.64	0.17	3.22	0.68	0.18	3.75	0.69	0.67	3.35
9.	90	0.13	3.20	0.52	0.14	3.36	0.56	0.13	3.89	0.52	0.53	3.48
10.	110	0.15	3.35	0.45	0.16	3.52	0.48	0.17	4.05	0.51	0.48	3.64
11.	130	0.15	3.50	0.45	0.16	3.68	0.48	0.17	4.22	0.51	0.48	3.80

TABLE A_4

DETERMINATION OF GOOD NESS OF FIT OF EQUATION $y = at^b$

S.No.	y observed in cm	Time (t) in min	$\log_{10} y$	$\log_{10} t$	y calculated in cm $y = at^b$	Deviation %
1	2	3	4	5	6	7
1.	1.16	5	0.0645	0.6989	1.198	+3.27
2.	1.75	10	0.2420	1.0000	1.625	-7.14
3.	2.09	15	0.3201	1.1761	1.942	-7.08
4.	2.50	25	0.3979	1.3979	2.432	-2.72
5.	2.75	35	0.4393	1.5441	2.820	+2.55
6.	2.99	45	0.4757	1.6532	3.149	+5.31
7.	3.18	60	0.5019	1.7782	3.575	+12.42
8.	3.35	75	0.5251	1.8751	3.943	+17.70
9.	3.48	90	0.5458	1.9542	4.272	+22.76
10.	3.64	110	0.5611	2.0414	4.667	+28.21
11.	3.80	130	0.5798	2.1139	5.023	+32.18

APPENDIX B

TABLE B_1 WATER STORAGE EFFICIENCY AND WATER APPLICATION EFFICIENCY DURING FIRST IRRIGATION

S. No.	Posi-tion	Depth of sampl-ing in cm	P_{w2} %	P_{w1} %	P_w %	Av. depth of water stored in root zone in cm	Water stored in root zone in lit	Water uti-lized by plants in lit	Water deli-vered to the field in lit	F.C. $-P_{w1}$ %	Water needed to fill root zone in cm	Water app. effie-iency %	Water storage effieiency %
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.		30	20.28	14.12	6.16					8.38			
2.	A	60	20.80	16.74	4.06					5.76			
3.		90	21.10	16.24	4.86					6.26			
4.		30	20.17	13.34	6.83					9.16			
5.	B	60	20.00	16.24	3.76	7.57	11696	618	14400	6.26	9.67	85.50	80.35
6.		90	21.17	16.92	4.25					5.58			
7.		30	22.42	14.72	7.77					7.78			
8.	C	60	21.46	16.25	5.21					6.25			
9.		90	21.79	16.71	5.08					5.79			
10.		30	20.76	11.94	8.82					10.56			
11.	D	60	20.19	14.90	5.99					7.60			
12.		90	22.13	12.58	9.55					9.92			
13.		30	19.04	13.11	5.93					9.39			
14.	E	60	19.52	16.57	2.95	6.81	8948.3	526	11376	5.93	10.26	83.28	68.32
15.		90	19.15	18.39	0.76					4.11			

TABLE B_1. (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
16.		30	18.73	14.81	3.92					7.69			
17.	F	60	20.38	17.50	2.88					5.0			
18.		90	20.05	17.71	2.34					4.79			
19.		30	21.01	13.19	7.82					9.31			
20.	G	60	19.79	17.05	2.74					5.45			
21.		90	21.08	17.39	3.69					5.11			
22.		30	20.00	12.80	7.20					9.70			
23.	H	60	22.16	15.17	6.99	9.07	13695	604	15552	7.33	11.5	91.90	80.60
24.		90	20.23	15.59	4.64					6.91			
25.		30	21.25	11.15	10.10					11.35			
26.	I	60	20.78	14.06	6.72					8.44			
27.		90	20.78	13.28	7.50					9.22			

APPENDIX B

TABLE B_2 WATER STORAGE EFFICIENCY AND WATER APPLICATION EFFICIENCY DURING SECOND IRRIGATION

S. No.	Position	Depth of sampling in cm	P_{w2} %	P_{w1} %	P_w %	Av. depth of water stored in root zone in cm	Water stored in root zone in lit	Water utilized by plants in lit	Water delivered to the field in lit	F.C. $-P_{w1}$ %	Water needed to fill root zone in cm	Water appli. efficiency %	Water storage efficiency %
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	30	30	18.08	13.06	6.02					9.44			
2.	A	60	21.06	14.98	6.08					7.52			
3.		90	21.82	16.16	5.66					6.34			
4.		30	18.67	12.37	6.30					10.13			
5.	B	60	20.38	14.89	5.49	8.767	13545	927	16063	7.61	11.48	90.10	78.95
6.		90	20.64	15.57	5.07					6.93			
7.		30	19.77	12.60	7.17					9.90			
8.	C	60	21.52	14.59	6.93					7.91			
9.		90	22.04	15.59	6.45					6.91			
10.		30	19.09	12.24	6.85					10.26			
11.	D	60	19.46	14.17	5.29					8.33			
12.		90	19.48	15.41	4.07					7.09			
13.		30	20.93	11.04	9.89					11.46			
14.	E	60	20.77	12.11	8.66	8.86	11642	788	13095	10.39	12.40	94.92	73.87
15.		90	19.26	15.69	3.57					6.81			

TABLE B_2 (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
16.		30	20.07	12.63	7.44					9.87			
17.	F	60	20.09	14.65	5.44					7.85			
18.		90	20.69	16.03	4.66					6.47			
19.		30	20.01	13.63	6.38					8.87			
20.	G	60	19.81	16.15	3.66					6.35			
21.		90	19.42	15.67	3.75					6.83			
22.		30	21.38	12.46	8.92					10.04			
23.	H	60	20.40	15.13	5.27	8.77	13243	906	16238	7.37	11.75	87.13	77.19
24.		90	20.34	15.52	4.82					6.98			
25.		30	19.26	11.29	7.97					11.21			
26.	I	60	20.89	12.23	8.66					10.27			
27.		90	21.77	16.03	5.74					6.47			

TABLE B_3

WATER DISTRIBUTION EFFICIENCY

S. No.	Av. of numerical deviation from Av. depth of water stored during irrigation (y) cm	Av. depth of water stored during irrigation ($\bar{d}$) cm	Distribution efficiency $Ed = (1 - \frac{y}{d}) X 100$ %
1	2	3	4
1.	0.67	7.57	91.15
2.	3.18	6.81	53.25
3.	1.636	9.07	81.96
1.	0.70	8.767	92.02
2.	1.08	8.86	87.77
3.	1.43	8.77	83.69

TABLE B_4

COMPARATIVE CHART FOR APPLICATION, WATER STORAGE AND DISTRIBUTION EFFICIENCIES

S.No.	Water application efficiency in %	Water storage efficiency in %	Water distribution efficiency in %
1	2	3	4
1.	85.50	80.35	91.15
2.	83.28	68.32	53.25
3.	91.90	80.60	81.96
1.	90.10	78.95	92.02
2.	94.92	73.87	87.77
3.	87.13	77.19	83.69

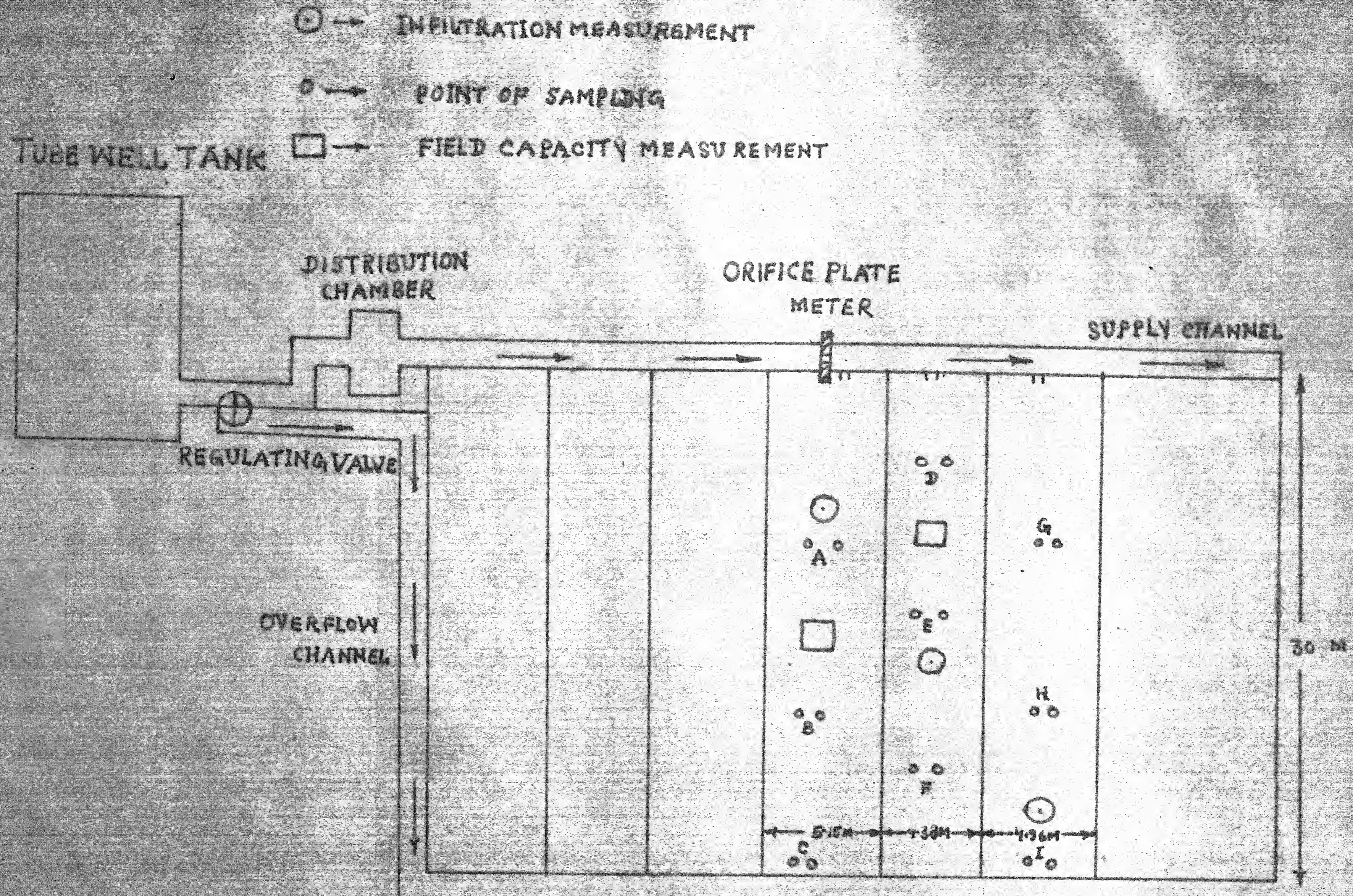


FIG.(1): LAYOUT OF EXPERIMENTAL FIELD

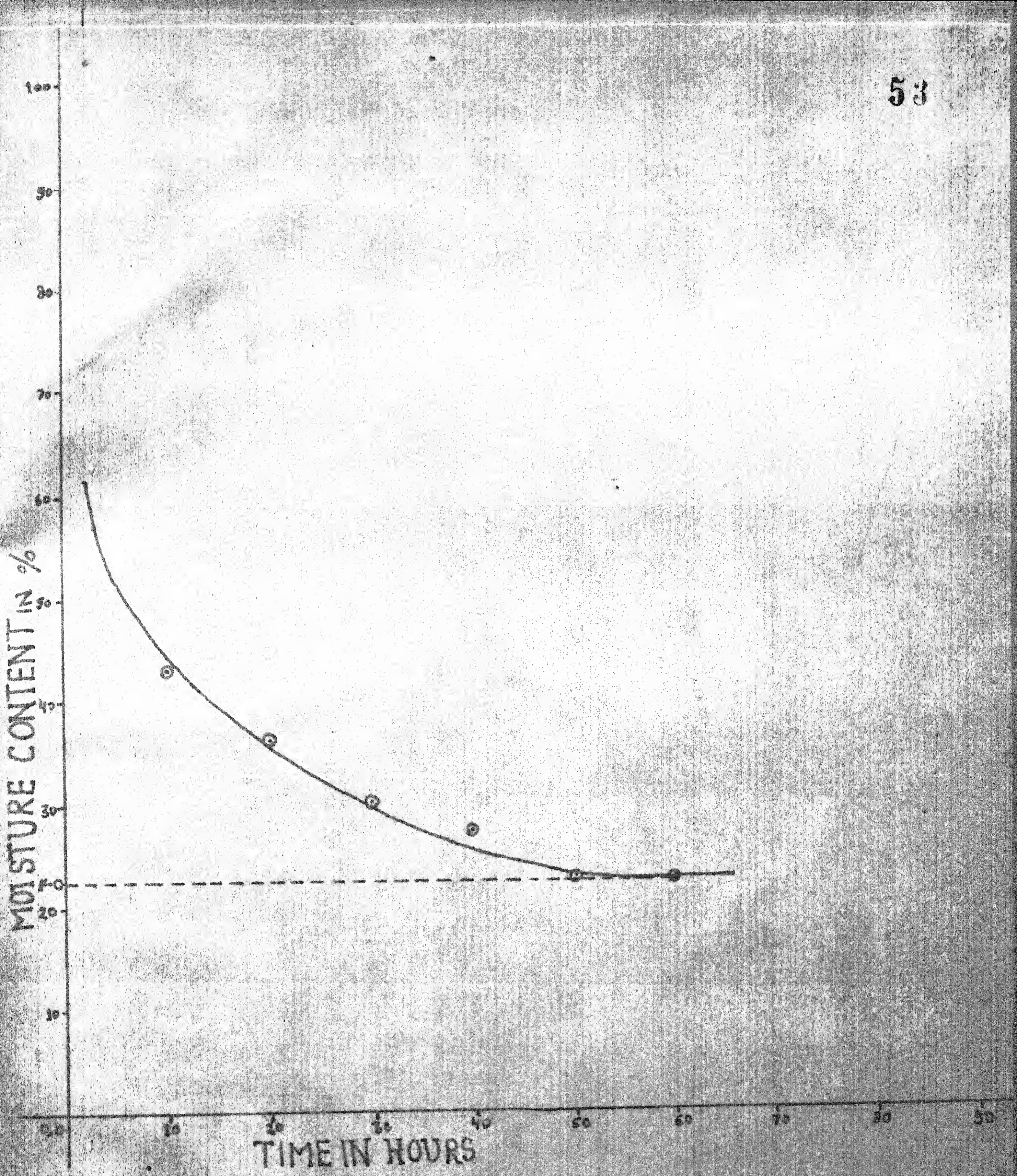
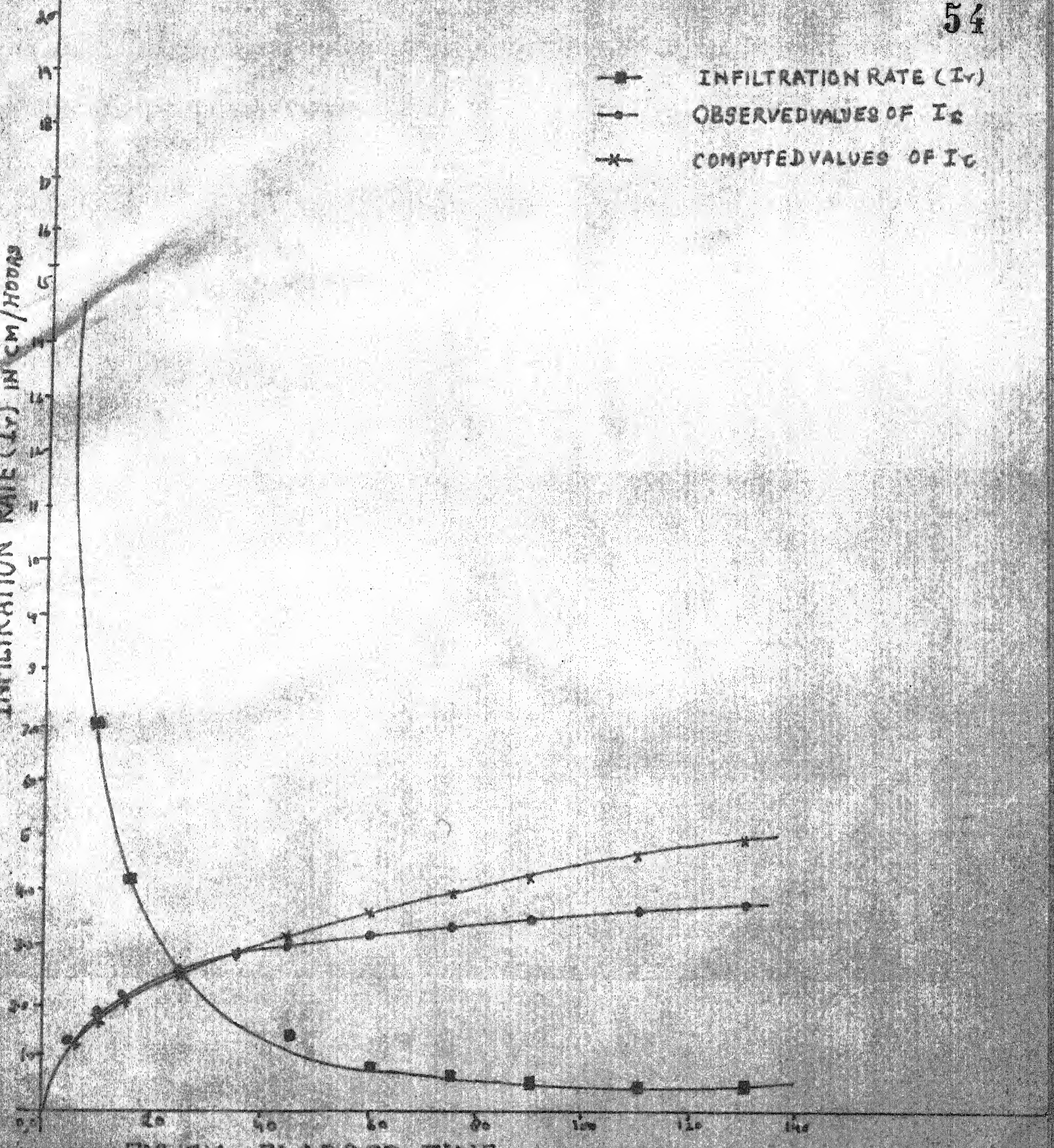


FIG.(2): PLOT OF M.C. Vs TIME FOR DETERMINATION OF F.C.



FIG(3): ELAPSED TIME IN MINUTES

PLOT OF ACCU. INFILTRATION & INFILTRATION RATE AGAINST ELAPSED TIME (ON THE BASIS OF DATA REPRESENTED IN TABLE A_3)

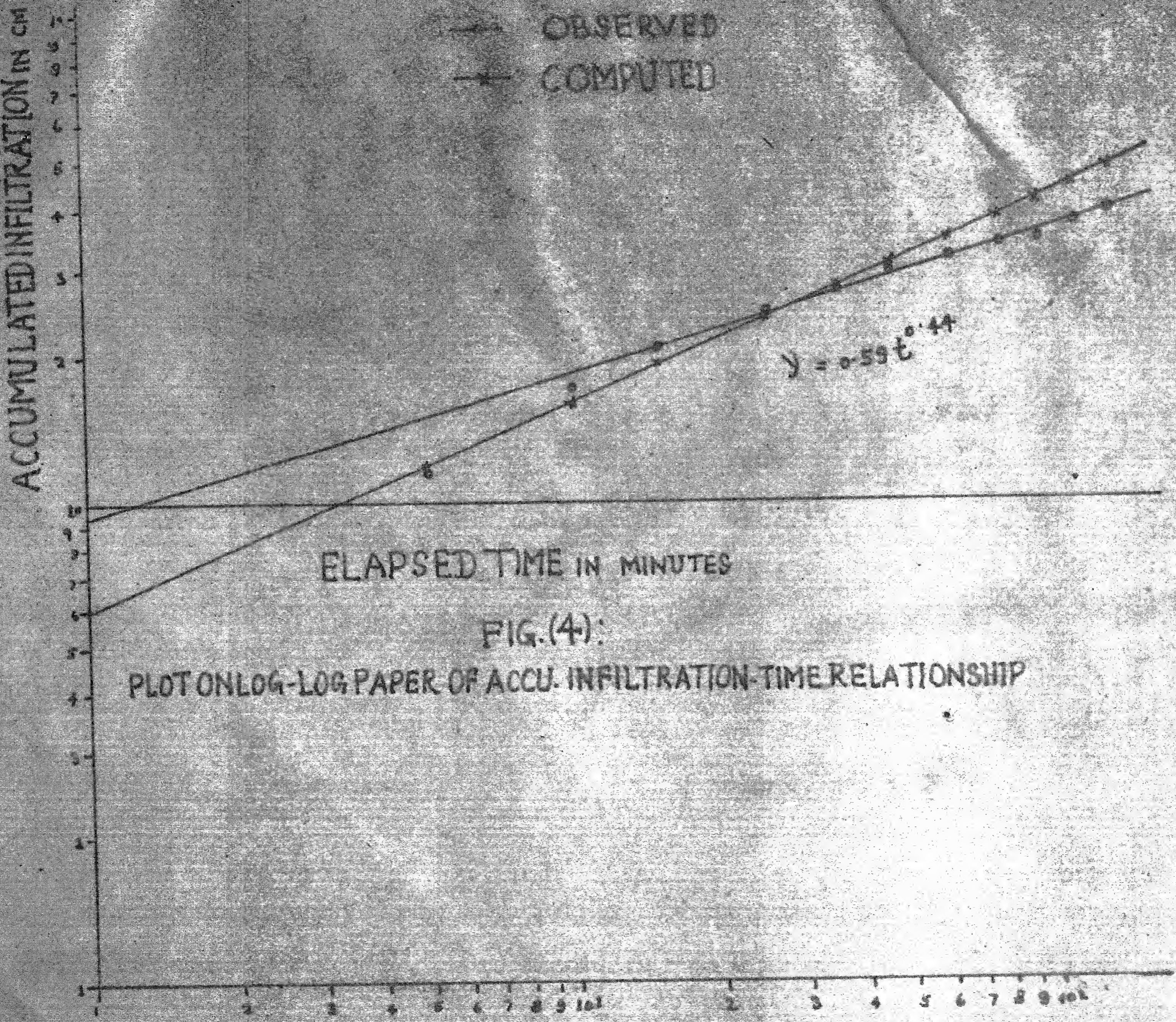


FIG. (4):

PLOT ON LOG-LOG PAPER OF ACCU. INFILTRATION-TIME RELATIONSHIP

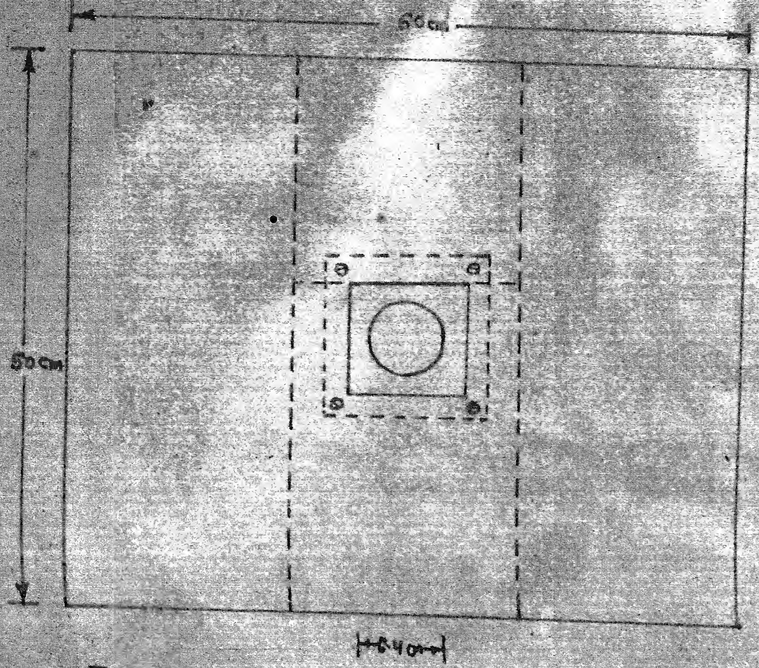


FIG 5.1 FRONT VIEW OF U/S SIDE

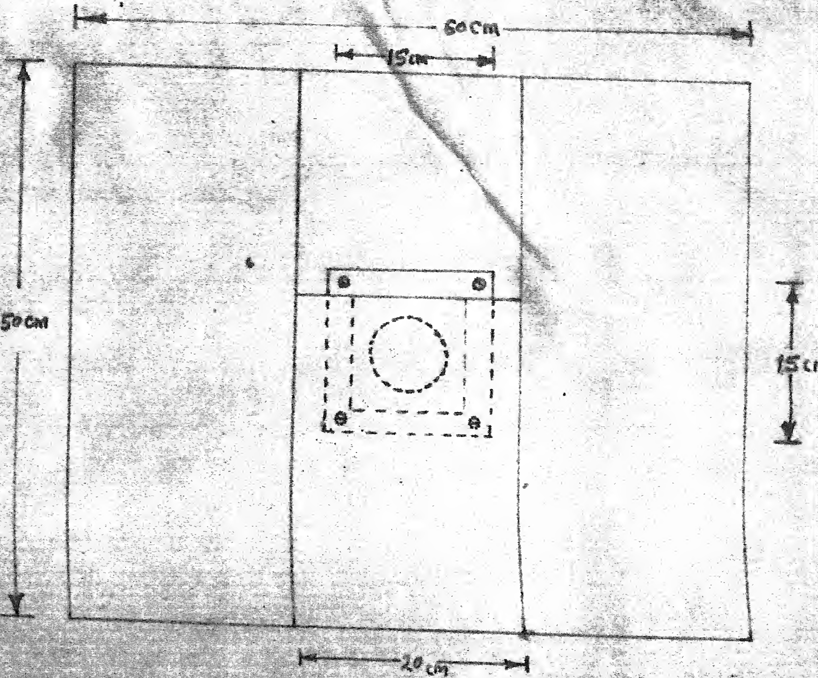


FIG 5.2 FRONT VIEW OF D/S SIDE

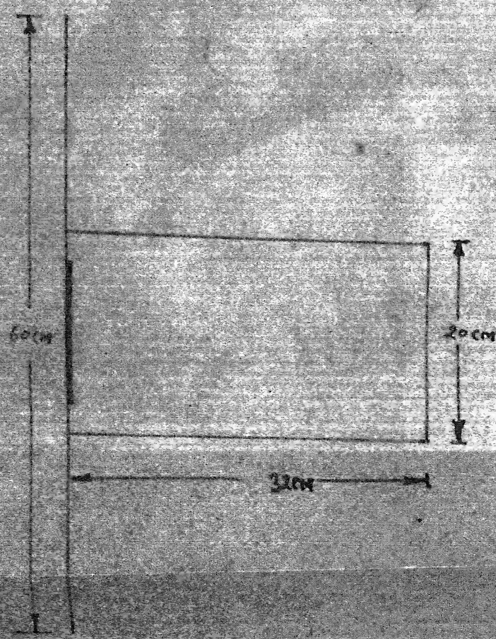


FIG 5.3 TOP VIEW

FIG 5.-DETAILS OF SUBMERGED ORIFICE PLATEMETER